Radiation Physics Note 61

LANDAUER NEUTRON DOSIMETER TESTING

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I. Introduction

During August 1986, a number of tests were concluded to compare the performance of two of Landauer's fast neutron dosimeters.

Monomer allyl diglycol carbonate, trade name CR-39, is placed in contact with a charged particle radiator made of polyethylene. Recoil protons emerging from the radiator penetrate the CR-39 causing damage which is chemically enhanced using a caustic solution. This results in etched tracks which can be counted under magnification.

Kodak NTA film is a special fine grained film, typically 25 to 35 µm thick. Neutrons are detected by the trail of ionization from charged particles released by (n,p) reactions in the film. The film is then developed, and the tracks counted.

The purpose of the tests was to determine the following:

- Differences in "latent image" fading
- Interference from gamma exposures
- The effect of the use of a phantom
- Lower limit of detection
- Angular dependence in a field generated by a stationary point source

There was no attempt to determine the energy dependence of either dosimeter. The study involved exposure to Pu-Be neutrons only.

II. General Procedures

The ^{238}Pu-Be source (238 Be-7.2-1) was placed on an aluminum support in the upstairs calibration room at Site 68. The dosimeters were taped to a 5 gallon water filled polyethylene jug which served as a phantom. The dosimeters were irradiated at a distance of 1.0 meter from the source. Dosimeters were irradiated in pairs (at least) or in groups of three or more where the geometry would permit. Only one parameter was varied for each test. (For example, all dosimeters were processed promptly except for the fading tests). The expected doses were determined by decay correcting the neutron source emission rate data provided by the manufacturer.

Gamma irradiations were done using the Site 68 ^{137}Cs beam projector. Control badges were submitted for each set of badges returned for processing.

III. Discussion

A. Fading Study

Badges were exposed to a nominal 100 mrem neutron dose and then sent in for processing in a staggered schedule which resulted in processing delays between 1 and 53 days. The results (see Figure 1) indicate considerable fading after 15 days and are in good agreement with the results obtained at higher doses by Couch and Salsbury (Co85). Assuming the fading to be linear with time, the rate of fading in both this study and (Co85) is about 2% per day. In contrast, the CR-39 exhibited less than 20% fading, even after 53 days. It should be noted that the normal film badge handling cycle delays processing up to 42 days after the printed wear date. This fading effect, which is well known has prompted Landauer to recommend 2 week badge periods for NTA.

B. Mixed Field

Two sets of dosimeters were irradiated in mixed fields. Both sets were processed without delay. A low dose set was exposed to a nominal 100 mrem neutron and from 500 to 750 mR gamma. The high dose set was exposed to the levels specified in our annual RFQ to Landauer, which is 500 mrem neutron in the presence of 5000 mR gamma. Despite our annual RFQ specification, Wheeler (Wh82) quotes 3000 mR gamma exposure as the level at which NTA neutron readout is precluded. Additional promotional information available from Landauer sets this NTA limit at the 1000 mR level.

In any case, as the results in Table 1 indicate, both dosimeters responded acceptably to the low dose set, but only the CR-39 was able to detect the neutron exposure in the presence of 5000 mR gamma. This result is in good agreement with the measurements recently made by Salsbury and Yurista (Sa86).

C. Effect of Phantom

The use of a phantom is specified by the draft DOELAP Order. Previous neutron exposure studies conducted at Fermilab have been typically done without a phantom. NTA, CR-39 and Neutrak I have been deployed as area monitors for years without the use of phantoms. As the results in Table 2 indicate, the CR-39 badges are essentially unaffected by the absence of a phantom, while the NTAs read slightly lower than other NTAs irradiated under otherwise ideal conditions. Considering the statistical fluctuation within this group however, the effect does not appear significant.

D. Lower Limit of Detection

Although the lower limit of detection for a dosimeter is a function of other relevant parameters, such as irradiation geometry and fading time, the purpose of this study was to grossly approximate the level at which the dosimeter becomes useless, even under the best conditions. The results are summarized in Table 3. It is shown that under otherwise ideal conditions, the NTA performed acceptably down to 30 mrem. Since the CR-39 performed at the 50% level between 30 and 50 mrem, the LLD is certainly higher than the advertised 20 mrem, but probably ≤50 mrem.

This is clearly a test which requires large numbers of dosimeter irradiations to properly determine the LLD. At such low-levels, the test is considerably dependent upon Landauer's practice of reporting doses in increments of 10 mrem.

E. Angular Dependence

This test was included because the draft DOELAP accreditation procedure calls for each processor to conduct such testing and report the results to DOE. There is presently no performance standard, although there is a testing procedure outlined. Because of the variables involved in determining fluence contributions from scattering, the validity of the testing procedure is being questioned by Landauer.

According to DOELAP, the badge to beam angle is varied by rotating the phantom along its vertical axis. Under this condition, the badge to phantom orientation remains constant. Landauer (Yo86) has made the argument that in order to properly test the performance of the dosimeter, it should be rotated with respect to the phantom.

Knowing that this issue would not be resolved for some time, it was decided to test small numbers of dosimeters under a variety of conditions to estimate the magnitude of the controversy. The results in Table 4 indicate why Landauer is so concerned about angular dependence testing criteria. The response was low as well as inconsistent. Some of the inconsistency may be attributable to the design of the irradiation jig used to position the dosimeters, which permitted small deviations from the nominal angles.

There is still no evidence to demonstrate that either of these two procedures is sufficient to test angular dependence under real conditions. Clearly, few instances of true personnel neutron exposure can be adequately modeled by a static irradiation.

IV. Summary

Although it has been acknowledged that the only purpose of the NTA is to serve as a neutron exposure "flag," the fading problems coupled with our monthly exchange period and half frequency of late badge turn-ins call into question the level at which this flag would actually be triggered. Exposures as high as 124 mrem were completely missed at 32 days after irradiation. One month late badges could be processed as late as 72 days after an exposure incident. Even if we were interested in flagging high doses, gamma interference problems considerably limit NTA's use for this purpose. Accident dosimetry is further complicated by the upper limit of the Kodak $X\beta\gamma$ film.

The CR-39 device is far from an ideal neutron dosimeter, since it may have some angular dependencies, and its very high energy response is not well known. These uncertainties however appear to be balanced by its excellent performance in the fading and gamma interference tests. A comparison of characteristics compiled from this study and Landauer literature appears as Table 5.

V. Comments

It would be most helpful to be able to irradiate large numbers of dosimeters in order to minimize Landauer's random error, but the flux of 238 Be-7.2-1 is only sufficient to produce 100 mrem in a 5 hour period. This suggests the need for a higher flux source.

I would like to thank Al Wiggin for his help in setting up the early irradiations.

References

Co85 Couch J.G. and Salsbury W.C., "A Study of Neutron Track Fading in NTA Film Dosimeters," R.P. Note 54, May 1985.

Wh82 Wheeler R.V., "Addressing the Personnel Neutron Dosimetry Problem at Accelerators," Presented at HPS Orlando Midyear Topical Meeting, February 1982.

Yo86 Yoder C., Personal Communication.

Sa86 Salsbury W.C. and Yurista P., "Dosimetry Comparisons at AP-10."

Figure 1

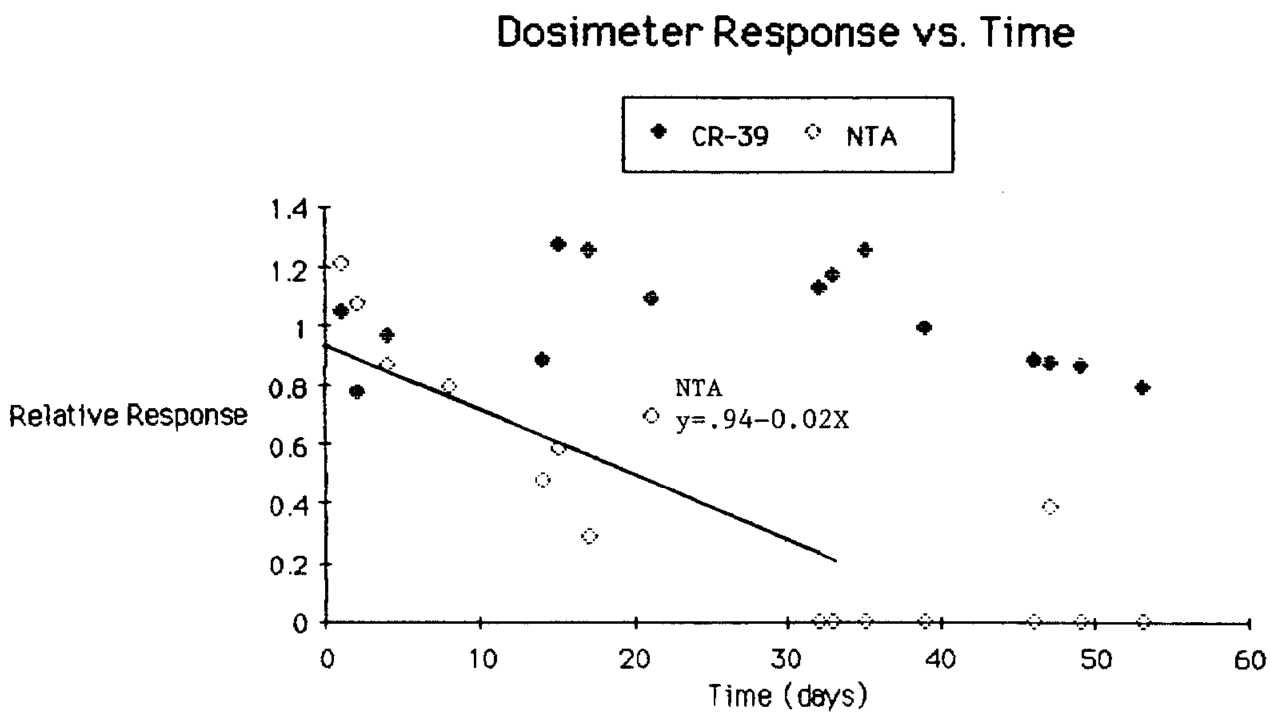
Dosimeter Response vs. Time
CR-39
NTA
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Relative Response
NTA
y=.94-0.02X
0
10
20
30
40
50
60
Time (days)

Table 1

Mixed Field Measurements

CR-39

Badge	Expected(γ)	Result(γ)	R/E(γ)	Expected(n)	Result(n)	R/E(n)
99156	675	630	0.93	112	140	1.25
99157	500	440	0.88	112	---	- Lost Data
99158	625	530	0.85	112	120	1.07
99159	750	700	0.93	112	100	0.89
			x=0.89			x=1.07
99174	4900	4440	0.91	485	420	0.87
99170	4900	3910	0.70	485	440	0.91
			x=0.85			x=0.89

NTA

Badge	Expected(γ)	Result(γ)	R/E(γ)	Expected(n)	Result(n)	R/E(n)
69713	675	590	0.87	112	80	0.71
69695	500	440	0.88	112	110	0.98
69711	625	530	0.85	112	80	0.71
69731	750	640	0.85	112	80	0.71
			x=0.86			x=0.78
70225	4900	3970	0.81	485	DH*	---
70240	4900	4150	0.85	485	DH	---
			x=0.82			

*DH Note indicates gamma exposure too high for NTA readout

Table 2

Effect of Phantom

CR-39

Badge	Expected	Result	R/E
99152	99	110	1.11
99153	99	130	1.31
99154	99	110	1.01
99155	99	90	0.91
			x=1.08

NTA

Badge	Expected	Result	R/E
69705	99	80	0.81
69706	99	70	0.71
69701	99	90	0.91
69702	99	100	1.01
			x=0.86

Table 3

Lower Limit of Detection

CR-39

Badge	Expected	Result	R/E
99162	29	0	---
99165	29	30	1.03
99164	52	40	0.77
99161	52	0	---
99166	75	70	0.93
99163	75	70	0.93

NTA

Badge	Expected	Result	R/E
70524	29	30	1.03
70208	29	30	1.03
70126	52	70	1.35
70108	52	70	1.35
70226	75	40	0.53
70543	75	70	0.93

Table 4a

Angular Dependence Case 1
Badge rotated on its vertical axis with respect to the phantom

CR-39

0°

Badge	Expected	Result	R/E
99137	108	110	1.02
99138	108	110	1.02
99139	108	110	1.02

90°

Badge	Expected	Result	R/E
99147	119	M	---
99148	119	M	---
99149	119	M	---

45°

Badge	Expected	Result	R/E
99144	128	20	0.16
99145	128	M	---
99146	128	20	0.16

180°

Badge	Expected	Result	R/E
99140	108	70	0.65
99141	108	40	0.37
99142	108	60	0.56

NTA

0°

Badge	Expected	Result	R/E
69938	108	110	1.02
69911	108	100	0.93
69944	108	100	0.93

90°

Badge	Expected	Result	R/E
69703	119	60	0.50
69692	119	60	0.50
69696	119	60	0.50

45°

Badge	Expected	Result	R/E
69948	128	90	0.70
69538	128	80	0.63
69542	128	90	0.70

180°

Badge	Expected	Result	R/E
69935	108	110	1.02
69912	108	150	1.39
69934	108	120	1.11

Table 4b

Angular Dependence Case 2
Badges on phantom normally, but phantom rotated 45° on its vertical axis

CR-39				NTA			
Badge	Expected	Result	R/E	Badge	Expected	Result	R/E
99173	121	30	0.25	70130	121	60	0.50
99171	121	30	0.25	70219	121	100	0.83

Table 4c

Angular Dependence Case 3
Badges rotated 45° on their horizontal axis with respect to the phantom

CR-39				NTA			
Badge	Expected	Result	R/E	Badge	Expected	Result	R/E
99172	121	80	0.66	70212	121	110	0.91
99169	121	60	0.50	70113	131	100	0.83

Table 5

Comparison of Characteristics of NTA and CR-39

Dosimeter Type	Advantages	Disadvantages
CR-39	1. Little fading with time 2. No gamma interference 3. Good response to intermediate energy neutrons	1. Response drops at sharp angles of incidence 2. Poor response to neutrons >15 MeV 3. Higher cost \$4.50
NTA	1. Less angular dependence than CR-39 2. Slower drop-off in energy response >15 MeV 3. Low cost \$2.50	1. Significant gamma interference 2. Serious fading with time 3. No response to intermediate energy neutrons